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MOOREITE, A NEW MINERAL, AND FLUOBORITE FROM STERLING HILL, NEW JERSEY

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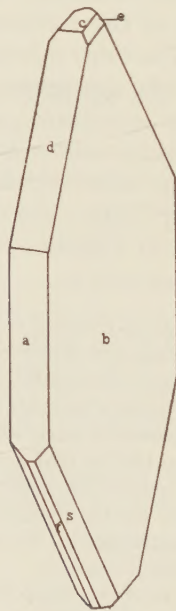
The minerals here described occur in intimate association with altered pyrochroite, rhodochrosite and zincite, in a vein in normal calcite-franklinite-willemite ore from the Sterling Hill Zinc mines. The willemite in one of the specimens examined, is replaced, near the vein, by brown serpentine ($n = 1.56$). The cavities in the pyrochroite are lined, and some of the crevices are filled, with glassy white tabular crystals which, upon investigation, proved to be a new mineral, for which the name mooreite is here proposed, in honor of Dr. Gideon E. Moore*, an early investigator of Sterling Hill and Franklin minerals. A closely related bluish-white mineral filling some of the crevices in the pyrochroite is termed here δ -mooreite. The other mineral occurring in the veins is a hair-like material in fluffy aggregates very loosely bound together, filling cavities in the pyrochroite, and covering the crystals of mooreite. Analyses of this material indicate that it is essentially a basic borate of magnesium, identical with the new mineral fluoborite, recently described by Geijer.¹ On one specimen were found some fibrous white rosettes of willemite which resemble the fluoborite and are easily confused with it.

* Gideon E. Moore, chemist of the Passaic Zinc Company in 1872 and of its successors until 1895. He described the minerals brushite, chalcophanite and hetaerolite, the two latter first found at Sterling Hill. Moore was born in New York in 1842 and died there in 1895. He was a graduate of Yale and took his Ph.D. in Heidelberg in 1869. His first professional work was as chemist for the Gould & Curry Mine on the Comstock from 1863 to 1867 and he then studied the minerals of that famous lode but did not publish his results. In later years he took out several patents in connection with the metallurgical treatment of Franklin zinc ores and others relating to organic chemistry. We are indebted for these facts to the Librarian of the New Jersey Zinc Company.

¹ *Geol. För. Förh.*, Stockholm, Jan.-Feb. 1926, p. 85, Vol. 48, pt. 1. *Sveriges Geol. Undersökning*, Ser. C., No. 343, Årsbok 20 (1926), No. 4.

MOOREITE
CRYSTALLOGRAPHY

Mooreite is monoclinic. The crystals are tabular and generally in subparallel aggregates grouped on the clinopinacoid. Of the many crystals studied, only a few were of a quality sufficiently good to yield moderately accurate measurements, the remainder were etched, striated, or distorted by subparallel growth. The angle table gives the measured angles together with the elements and angles calculated from them. The elements have been calculated from weighted averages in the making of which single good readings have been given preference over many rather poor ones, so that the elements are probably more accurate than an inspection of the measured angles would indicate. The principal forms of the crystal (fig. 1.) are b (010), always the largest faces on the crystal, d (101) present as long narrow faces usually having mediocre reflection surfaces and r ($\bar{1}11$) as long narrow line faces with good reflections. The other forms occurred on most crystals but were not used in the calculations because of their inferior quality. There



Mooreite, Franklin, New Jersey

were a few occurrences of c (001) which gave fairly good direct measurements of the inclination of the axes, and these were used in preference to indirect methods of computing the inclination.

A number of small doubly terminated crystals were found almost ideal in development.

No crystals of δ -mooreite were found, but it is thought to be monoclinic also, from its optical properties.

TABLE I
ANGLE TABLE—MOOREITE

$p_0 = 1.743$	$a = .553$
$q_0 = .813$	$c = .963$
$e = .537$	$\beta = 142^\circ 27'$
$\mu = 57^\circ 33'$	

Letter	Symbol	Calculated		Observed maximum		Observed minimum		Average	
		ϕ	ρ	ϕ	ρ	ϕ	ρ	ϕ	ρ
c	001	90° 00'	32° 27'		32° 42'		32° 16'		32° 27'
b	010	0°	90° 00'						
a	100	90° 00'	90° 00'						
d	101	90° 00'	69° 41'		70° 23'		69° 34'		69° 54'
e	101	90° 00'	55° 01'						55° 00'
f	102	90° 00'	21° 39'						21° 29'
g	011	33° 27'	49° 06'	32° 02'	49° 06'	33° 15'	49° 14'	33° 11'	49° 09'
p	121	54° 30'	73° 13'	55° 01'	73° 18'	54° 23'	73° 06'	54° 42'	73° 12'
r	111	56° 01'	59° 52'	56° 15'	59° 51'	55° 56'	59° 48'	56° 03'	59° 50'
t	113	9° 12'	18° 01'	— 9° 24'	18° 05'	9° 22'	17° 57'	9° 23'	18° 01'
v	115	49° 07'	16° 26'	49° 11'	16° 18'	48° 51'	16° 15'	49° 01'	16° 17'

CHEMICAL COMPOSITION

Mooreite is a very basic, hydrous sulphate of magnesium, manganese and zinc. The two types differ principally in the relative proportions of these three bases.

TABLE II
TABLE OF ANALYSES OF MOOREITE AND δ -MOOREITE

1. and 2. Separate complete analyses of mooreite.
3. Average of 1 and 2 omitting unessentials and recalculated to 100 per cent.
4. Molecular ratios of 3.

5. Analysis of δ -Mooreite.

6. Molecular ratios of 5.

1	2	3	4	5	6
MgO 25.41	24.98	25.38	.629	17.27	.427
MnO 11.46	12.24	11.93	.167	17.98	.253
ZnO 24.57	24.24	24.58	.300	26.30	.323
SO ₃ 11.11	10.73	10.99	.136 = $1 \times .136$	11.64	.145 = $1 \times .145$
H ₂ O 27.20	26.67	27.12	$1.506 = 11 \times .137$	26.39	$1.466 = 10 \times .146$
B ₂ O ₃ Present				Present	
SiO ₂ 0.06				0.08	
CaCO ₃	0.89				
99.81	99.75	100.00		99.66	

The formulas to which these analyses lead are:

Mooreite $8 \text{ RO} \cdot \text{SO}_3 \cdot 11 \text{H}_2\text{O}$ where $\text{R is Mg:Mn:Zn} = 4:1:2$.

δ -Mooreite $7 \text{ RO} \cdot \text{SO}_3 \cdot 10 \text{H}_2\text{O}$ where $\text{R is Mg:Mn:Zn} = 5:3:4$.
or they may be written:

Mooreite $7 \text{R}(\text{OH})_2 \cdot \text{RSO}_4 \cdot 4 \text{H}_2\text{O}$

δ -Mooreite $6 \text{R}(\text{OH})_2 \cdot \text{RSO}_4 \cdot 4 \text{H}_2\text{O}$

There are no known minerals to which mooreite is closely related. Nor can it be said which of the two varieties is the more typical chemically for it could not be determined whether or not one of them was forming at the expense of the other. δ -mooreite appeared to be replacing pyrochroite in one place which might be interpreted as meaning that it was first to form and was intermediate between the manganese hydrate, pyrochroite, and the magnesium-rich mooreite.

PHYSICAL AND OPTICAL PROPERTIES

Mooreite is clear, glassy white in color, with a perfect cleavage parallel to b (010). δ -mooreite is bluish white, granular, and has a less perfect pinacoidal cleavage. The hardness of both varieties is about 3. The specific gravity was determined by the pycnometer method:

Mooreite = 2.470

δ -Mooreite = 2.665

The optical characters, determined by the immersion method are compared below:

MOOREITE	δ -MOOREITE
Biaxial negative, $2V = 50^\circ \pm$	Biaxial negative, $2V = 40^\circ \pm$
$X = b$; $Z \wedge c = 44^\circ$	
$\rho > \nu$ perceptible	
$\alpha = 1.533$	$\alpha = 1.570$
$\beta = 1.545$	$\beta = 1.584$
$\gamma = 1.547$	$\gamma = 1.585$

FLUOBORITE

On the previous page mention was made of the occurrence, with mooreite, of fluoborite. The material in most specimens consists of a fluff of loosely felted fibers unattached in the cavity and later in origin than all of the associated minerals. It was found, however, that the borate had begun to be deposited at least as early as the mooreite which contains fibers of it. This fluffy material is so light in weight that difficulty was experienced in obtaining a sufficient amount for analysis, and, as a matter of fact, the unusual difficulty of this particular analysis made necessary much preliminary work, so that a scarcity of material was encountered. In the course of the investigation new material was obtained consisting in part of fluoborite in a compact finely fibrous form intimately mixed with a hydrous carbonate probably closely related to hydrozincite, and in part as veinlets in an especially pure zincite from Sterling Hill. A specimen of the latter in the Harvard Museum had long been labelled hydrozincite. Upon closer examination it was found to contain veinlets of fluoborite comparatively free from impurities. The main mass of the specimen is the pure zincite referred to above, penetrating which are irregular areas of carbonates. The carbonates have been partially altered to a dull granular mass showing slickensided surfaces upon which the fluoborite veinlets are found. In a few instances the veins are fluorite. The analysis in Table III is of the fluoborite in this specimen. It is considered the best of the analyses made because the sample was practically free from impurities. Many difficulties were encountered in the preparation of a sample and in devising a satisfactory method of analysis. Fortunately the best sample was analyzed after considerable work had already been done on inferior material and the method, outlined in Table III had been devised.

TABLE III

ANALYSIS OF FLUOBORITE; L. H. BAUER, ANALYST

1. Fluorborite, analysis of material associated with zincite. 1.28 grams, about 97 per cent pure. (Cat. number 89379).
2. Molecular ratio of 1.
3. Carbonate impurity deducted as calcite (some MnCO_3).
4. Molecular ratio of 1 after deducting impurity.
5. Calculated composition for $6\text{RO} \cdot \text{B}_2\text{O}_3 \cdot 3(\text{F}_2, \text{H}_2\text{O})$.

PROCEDURE IN ANALYSIS

1.28+grams were used for analysis.

0.1512 gram was taken for determination of H_2O .

Ref. *Am. Jour. of Sci.*, V, 48, 3rd Series, 1894.

Freshly ignited C.P. CaO equivalent to $2\frac{1}{2}$ times the weight of the sample was taken as a retainer for the fluorine. C.P. anhydrous PbO as recommended by Penfield was found unsatisfactory.

0.1873 gram was taken for determination of CO_2 .

0.202 gram was taken for MgO , ZnO , MnO , and CaO ; these were determined by well known standard methods.

0.1918 gram was taken for determination of B_2O_3 . Distillation Method as Modified by Chapin. Ref. *Scott's Standard Methods of Chemical Analysis*, 4th Ed., Vol. I, page 87.

The sample was fused with twice its weight of C.P. SiO_2 and eight times an equal mixture of Na_2CO_3 and K_2CO_3 . Strict precautions as outlined by Chapin were observed in dissolving and transferring the HCl solution of the sample into the distillation flask.

This procedure was first tried with synthetic mixtures of C.P. CaF_2 and B_2O_3 .

0.1502 gram was taken for determination of fluorine. Ref. *Fresenius, Quant. Chem. Analysis*, Vol. II, page 1182. *Treadwell and Hall, Analytical Chemistry*, Vol. II, 7th ed., page 407. In the absence of silica the sample was fused as in the boron determination with twice its weight of C.P. SiO_2 and eight times an equal mixture of Na_2CO_3 and K_2CO_3 . The fusion was not blasted and all subsequent operations where possible were performed in platinum ware.

	1	2	3	4	5
MgO	60.07	1.487	.007	$1.538 = 6 \times .256$	67.38
ZnO	2.41	.030			
MnO	1.93	.028			
CaO	1.19	.021	.021	$.246 = 1 \times .246$	17.40
B_2O_3	17.25	.246			
F_2	17.60	.463			
H_2O	5.22	.290		$.753 = 3 \times .251$	17.00
CO_2	1.23	.028	.028		
	106.90				107.15
	7.41				7.15
	99.49				100.00

In Table IV are some of the analyses made on other samples. Analyses 3 and 4 of this table are on impure material before and after the easily soluble portion was removed. The fluoborite is difficultly soluble in acid. In analysis 4 of the acid treated portion, the fluorine and boric acid are found in amount, demanded by the fluoborite formula. There is, however, a deficiency in water, which may account for the low total. Analyses 1 and 2 of Table IV are of fluoborite with varying amounts of impurities.

TABLE IV
ANALYSES OF FLUOBORITE

1. Fluoborite from Sterling Hill, analysis of material associated with zincite. 85 per cent pure. Impurity calcite. L. H. Bauer, analyst.
2. Fluoborite from Sterling Hill, analysis of material associated with zincite. (Cat. No. 89345). Large impurity of hydrous carbonate probably $4\text{RO} \cdot \text{CO}_2 \cdot 3\text{H}_2\text{O}$.
3. Fluoborite from Sterling Hill, associated with mooreite. Large impurity of hydrous carbonate.
4. Fluoborite. Sample 3 after treatment with HCl (1:1) until effervescence ceased. The low total may be accounted for by the deficiency in the water as given.
5. Fluoborite from Norberg, Sweden. Analyst Dr. Bygden. $^*\text{SiO}_2, \text{Al}_2\text{O}_3, \text{Fe}_2\text{O}_3$.

	1.	2.	3.	4.	5.
MgO	48.00	29.16	46.33	62.07	61.65
ZnO	3.69	30.06	15.00	2.05	
MnO	6.10	8.55	4.13	2.09	0.05
CaO	7.36	0.17			
B ₂ O ₃	14.40	2.57	10.87	18.68	17.90
F	14.16	1.55	9.83	17.14	9.30
H ₂ O	4.55	16.13	10.62	1.29	10.78
CO ₂	6.87	11.64	5.22		1.36
SO ₃	0.45	0.14	0.27		2.16*
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	105.58	99.97	102.27	103.32	103.20
Less O for F ₂	5.96	.65	4.14	7.22	3.92
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	99.62	99.32	98.13	96.10	99.28

The best analysis leads to the formula: $6\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3(\text{F}_2, \text{H}_2\text{O})$ in which the ratio of water to fluorine is as 2:3. The ratio in fluoborite from Norberg is approximately as 12:5; the Sterling Hill occurrence is thus much richer in fluorine although the molec-

ular percentage of the two constituents combined remains the same in both occurrences. This seems to add weight to the assumption that the water and fluorine are mutually replaceable in this mineral and under suitable conditions we might reasonably expect a fluorine free "fluoborite." In this connection it is interesting to note that sussexite, the mineral which is probably most closely related to fluoborite, as was pointed out by Geiger, is free from fluorine.

PHYSICAL PROPERTIES OF FLUOBORITE

The fluoborite, associated with mooreite, from Sterling Hill is uniaxial negative (-), with $\omega=1.548$ and $\epsilon=1.518$. The specific gravity, determined by floating a loosely matted aggregate in clerici solution is 2.88. The fluoborite associated with zincite had the following properties. Uniaxial negative (-), $\omega=1.547$; $\epsilon=1.522$, and a specific gravity, determined on compact fibrous aggregates, of $2.92 \pm .01$. This value for the specific gravity is probably more accurate than the one given for the fluoborite associated with mooreite because the material used was more suited to such a determination.

It was not possible to determine the crystallographic nature of the material directly, as was the case with the type material, since fibers showed no hexagonal outline under the microscope and were far too small for goniometric study. Indirectly, however, by comparison of X-ray powder spectrographs of the type material and the Sterling Hill fluoborite, it was found that the structures of the two give essentially the same spectral lines.

CRYSTAL STRUCTURE TYPES

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INTRODUCTION

An enormous amount of information has been collected in recent years on the structure of crystals. Much of it is not in the domain of mineralogy, but a large part is becoming of ever increasing importance to this science. It is with this in mind that an attempt will be made to present a short review of some of the relations of structure types to one another.

V. M. Goldschmidt and his co-workers together with many others (see bibliography) have attempted to classify the known structures into definite types, and thus explain such properties as isomorphism, polymorphism, morphotropism, hardness, and optical properties.

ATOMIC ARRANGEMENTS AND TYPE STRUCTURES

The fundamental law governing the structure of crystals, according to V. M. Goldschmidt, may be expressed in the following words: *The structure of a crystal depends on the relative quantities, sizes, and deformability of its components.* The components may be atoms, ions and groups of atoms or ions.

Relative quantities, of course, are expressed in the chemical formula which tells us how many atoms of each element are contained in the molecule. The apparent radii of atoms and ions are now known at least approximately. We are not concerned in this study with the true radius of an atom or ion but with the effective radius, the radius of its sphere of influence, which it occupies in the structure of the crystal.

Deformability refers to the distortional or deforming behavior of atoms or ions towards their neighbors. This mutual influence on one another's electromagnetic fields causes atoms or ions to behave like compressible spheres. It also causes a decrease in the size of the apparent radii of the atoms or ions. In some elements, especially those that resemble in structure the inert gases, as for example O and F, Na, Ca, and Sr, the deformability is small. Therefore, oxides and fluorides approach the ideal conditions of packing of spheres most closely. In many other elements including S, Te, Se, Br, I, Fe, and certain radicals like OH, the deformability

is great enough to be a deciding factor in the production of structures containing them as well as in isomorphism, morphotropism and other physical properties.

For the present, let us imagine atoms or ions as incompressible spherical particles. *The electrostatic attraction causes each ion to be surrounded as closely as possible by ions of an opposite charge.* Definite geometrical arrangements are possible provided that the ions are all in contact. Figure 2 for example shows that a sphere *A* of a radius of 0.41 (the radius of *B*=1.00) can be placed between four spheres *B*, forming a square. *A* will touch each *B* sphere. Simple arrangements are:

Equilateral triangle	Fig. 1	Ratio A:B=0.15
Square	Fig. 2	" " 0.41
Tetrahedron	Fig. 3	" " 0.22
Octahedron	Fig. 2	" " 0.41
Cube	Fig. 4	" " 0.73

The radii of the smaller circles *A* in the figures 1-4, as compared to the larger ones *B*, give us the ratios which indicate how large an ion or atom *A* can be accommodated between a set of ions or atoms *B* and just be in contact with each *B* atom. Investigations of a large number of crystal structures has shown that ratios which are relatively much below those given are rarely if ever encountered. On the other hand, there is no theoretical reason why the smaller atom *A* could not be considerably increased in size for contact with the *B* ions would be maintained during this increase. Whenever the ratio of the *A* to the *B* ions had become the reciprocal of the ratio given above, the upper limit of the ratio would be reached. Since we are dealing with geometrical lattices which are repeated an indefinite number of times in all directions we see that the *A* ions "enclose" the *B* ions, the latter having the same relative size to the *A* ions now as the *A* ions had to the *B* ions before.

It is obvious from this discussion that the *relative sizes of ions and not their absolute sizes are important* as was formerly thought. If, however, strongly deforming or deformable ions or atoms are in the structure, size of ions may become of secondary consideration.

A study of structure models Figs. 5-17 shows that the familiar type of chemical valence cannot be identified in crystals. Re-

course must be had to the so-called valence coordinates as developed by Werner almost forty years ago. These coordinates are the shortest distances between the ions. They are shown in Figs. 5-17. No prediction as to the number of coordinates associated with an ion in a substance can be made with any degree of certainty. Regularities have been observed, however, according to which Goldschmidt (4, p. 23) has classified some structures into the following divisions:

- Coordinate number 1. Single molecules and lattices of them.
- Coordinate number 2. Double molecules and molecule chains and lattices.
- Coordinate number 3. Boron nitride and graphite structures. Each atom is bound to others by three bonds. Fig. 16.
- Coordinate number 4. Diamond, zincblende, wurtzite, and tetragonal "layer lattices." Four bonds for each atom or ion. Figs. 8, 9, 10.
- Coordinate number 6. Sodium chloride and nickel arsenide structure types. Six bonds for each atom or ion. Figs. 5 and 6.
- Coordinate number 8. Caesium chloride structure type. Eight bonds for each atom or ion. Fig. 7.

It will be noted that the structures enumerated (graphite and diamond excepted) are of the general formula MR which, of course, is the reason why the M and R atoms or ions in the structures have an equal number of valence coordinates.

In compounds of the formula MR_2 or M_2R the following coordinate numbers have been observed:

- 2 and 1. Single molecules and lattices of them.
- 4 and 2. α - and β -quartz, β -cristobalite and cuprite structure types. Figs. 12, 14, 15.
One atom or ion has two, and the oppositely charged 4 coordinates.
- 6 and 3. Cadmium iodide, molybdenite, rutile, octahedrite structure types. Figs. 13, 17.
- 8 and 4. Fluorite structure type. Fig. 11.

These types are not the only ones possible.

It is interesting to note in Table I the differences in chemical valence which may be found in the same type of structure. This, then, explains the apparent inconsistency in isomorphous mixtures where a trivalent element may be replaced by a tetravalent one or by a bivalent element.

That the radius of an element depends upon its electric charge has been pointed out by many investigators and was reviewed by E. T. Wherry in this journal.¹ The radius of the neutral atom then is quite different from that of the ion. For example, sulphur has a radius of about 1.03 Å when neutral, and about 1.8 Å when it has a negative charge of 2. In the positive state with a valence of 6, as for example in sulfate radicals, it shrinks to a radius of about 0.3 Å.

But even the radius of the same atom or ion in the same state with respect to its electric charge is not constant. The radius of a lattice particle depends partly upon the kind and number of neighbors it has as well as on the thermodynamic effects, such as pressure and temperature. Other things being equal, the greater the number of nearest neighbors the greater the apparent radius of the atom or ion. This is reasonable, for as may be seen in Figs. 3 and 4 there is more room between spheres arranged at the corners of a cube than spheres arranged at the corners of a tetrahedron. Also (and this is probably more important) the enclosed atom or ion is attracted by more electromagnetic fields in the one case than in the other, which tends to increase its radius.

Goldschmidt (4, p. 69) has published several instructive tables with reference to this matter. Assuming that the same compounds can occur in the different structure types (some of them occur in at least two or more) we find shrinkage of the apparent radii, that is, decreases in distances between neighboring atoms of opposite charge, as follows. The numbers following the types are the numbers of valence coordinates for each atom or ion.

Transition from	CsCl	type 8:8,	to NaCl	type 6:6,	shrinkage	3%
"	"	NaCl	" 6:6	" ZnS	" 4:4	" 5-7%
"	"	NaCl	" 6:6	" CaF ₂	" 8:4	" 3%
"	"	CaF ₂	" 8:4	" TiO ₂	" 6:3	" 3%
"	"	NaCl	" 6:6	" TiO ₂	" 6:3	" 6%
"	"	NaCl	" 6:6	" SiO ₂	" 4:2	" 6-10%

In some of these examples the shrinkage could be determined only indirectly for no direct comparisons of their structures are possible.

¹ *Am. Mineral.*, Vol. 14, p. 54. I cannot agree with Dr. Wherry on his proposal to substitute the symbol "*am.*" for Å. Å has been adopted internationally. The word ångstrom is not much more difficult to pronounce than the word ampere.

MORPHOTROPISM AND POLYMORPHISM

It is practically impossible to give an adequate review in a short paper of the large amount of material which has been collected by Goldschmidt and others on isomorphism and morphotropism. A discussion of some of the more important points follows.

It was shown above that in the transition from certain types to others a reduction of more than 5% may take place in the distances between ions. These types in which the shrinkage is considerable are not directly "commensurable" or comparable. There are a number of reasons why it must be assumed that the particles in one are not in the same state (whether ionic or atomic) as in the other. Goldschmidt (4, p. 75) gives the example of the incommensurable NaCl and zincblende. There is every reason to believe that the NaCl structure is made up of ions while the particles in ZnS may be atoms or at least are closer to that state than to the ionic state. In other words, the particles as atoms in structures of the ZnS type (Table I) show greater resemblance to the atoms in diamond than to the ions in the NaCl structure. Therefore, when comparing the properties of one structure with those of another, as for example in isomorphism, consistent results will probably be obtained only if the two structures are commensurable, *i.e.*, their particles are in the same state or condition.

Morphotropism or morphotropic change is the change from one structure type to another type brought about in such a manner that by chemical substitution the limits of the ratio of the atomic radii in the structure are exceeded, which then results in the new type. A greater degree of deformability of the replacing substance may have the same effect. Such a change of type can also occur in crystal structures without chemical substitution by changing the thermodynamic conditions under which it is stable. This is called polymorphism.

A study of the ratios of the atomic radii in the various types shows the following limits (Table II).

Such structures as MoS₂, Fig. 17, and boron nitride, Fig. 16, are called "layer lattices" on account of the arrangements of the particles in distinct layers. They are due to great deformability of their atoms or ions. No limits for ratios of their radii can be given at present.

TABLE II
RATIO $A:B$

TYPE	APPROX. LOWER LIMIT	APPROX. UPPER LIMIT
NaCl	0.41	2.41
CsCl	0.73	1.37
NiAs	0.40	1.89
ZnS	0.22	4.45
CaF ₂	0.73	4.45
TiO ₂	0.41	0.73
SiO ₂	0.22	0.41

It will be seen in Table II that the possible ranges of the radii for the types overlap in most cases. A selection then between these overlapping types, but within the limits given, is chiefly based on deformability of the particles as Goldschmidt has shown.

Several examples will be cited for illustrations. The rutile type has the valence coordinates 6 and 3 and a ratio $A:B$ between 0.41 and 0.73. If it is required to change to the quartz or cristobalite type with coordinates 4 and 2 and a ratio between 0.22 and 0.41, a smaller A particle or a larger B particle must be substituted in the rutile type. Of anions only F and O are available for those of higher atomic numbers are strongly deformable and their substitution might result in layer lattices or similar types. If we substitute, however, for Ti in rutile Si, we obtain a ratio of Si:O = 0.30 and the mineral cristobalite or quartz results.

From CeO₂ which crystallizes with the fluorite type, the rutile type SnO₂ may be obtained by substitution of Sn for Ce. Sn is sufficiently small to come within the range of the rutile ratio 0.41 to 0.73.

The limits of the ratio of the CsCl type are well within the range of those of the NaCl type. To bring about a change from the NaCl type to the CsCl we substitute an ion of greater deformability. For example, by the substitution of Tl for Rb in RbCl, which belongs to the NaCl type and has the ratio 0.82, TlCl with the same ratio is obtained because Tl has the same radius as Rb. But TlCl is of the CsCl type.

STRUCTURES CONTAINING RADICALS

We have not thus far mentioned structures containing such radicals as CO₃, SO₄, NO₃, etc. The existence of such radicals

seems to be almost entirely attributable to deformability of the ions concerned. The investigations by Fajan, Born, Heissenberg, Hund and others show that the following general statements are true.

(1) Deformability of an ion decreases with increasing positive valence and increases with increasing negative valence.

(2) Deformability decreases (valence being constant) with decreasing radius of the ions.

(3) The deforming influence of an ion increases with increasing positive or negative charge.

(4) The deforming influence of an ion increases (valence being constant) with decreasing radius of the ion.

This would make ions of C^{++++} , Si^{++++} , S^{+++} (in the sulfate radical), Al^{+++} , N^{++++} , highly deforming and O^{-} , and S^{-} , easily deformable ions. When these extremes meet, there result closely connected groups or radicals, usually with a strongly deforming ion in the center. That the bonds between the ions in the group are stronger than in the rest of the structure is also indicated by the fact that the distances between them may be smaller than would be expected from their normal behavior. For example, the distance $C-O$ in the CO_3 group of calcite is 1.25\AA , though the radius of O alone is usually 1.32\AA . In the SO_4 radical of $CaSO_4$, on the other hand, the distances between S^{++} and O^{-} are normal. The four O ions form a nearly regular tetrahedron about the S ion according to Wasatjerna.

There are also cases in which the radical has practically lost its identity due to the great deforming influence of the ions surrounding the radical. Such disruption is called counter-deformation (Kontra-polarisation) by Goldschmidt who also gives the following example (3, p. 67). In spinel $MgAl_2O_4$, the radical Al_2O_4 is no longer recognizable because of the strong counter deforming influence of the Mg ions. The O ions are now closer to the Mg ions than to the Al ions, though the radii of the ions would lead one to expect the reverse.

SUMMARY

An attempt has been made to present in a condensed form some of the recent investigations of crystal structure types especially those of Goldschmidt. Structure types and their valence coordi-

nate bonds are discussed and illustrated. Morphotropism, polymorphism, the formation of radicals due to the deformability of ions and the effects of counter-deformability are explained with the aid of simple structure types.

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Figures*

* Most of the figures (1-4 excepted) with slight modifications are taken from P. P. Ewald and C. Hermann (2).

Fig. 1. Equilateral triangle of spheres showing size of sphere which may be placed inside. Limit of ratio of radii $A:B=0.15$.

Fig. 2. Square. Limit $A:B=0.41$. The same ratio holds for the octahedron which we obtain from Fig. 2 by placing a B sphere above and one below the A sphere.

Fig. 3. Tetrahedral arrangement. Limit $A:B=0.22$. The dotted circle represents two spheres one above, the other below, the plane of the paper.

Fig. 4. Cubic arrangement of spheres. Limit $A:B=0.73$. Two spheres placed above the dotted circles will close the cube.

Fig. 5. Sodium chloride, NaCl . The lines connecting the ions are valence coordinates. The cation as well as the anion has six bonds to its nearest neighbors of opposite charge, which we might imagine at the corners of an octahedron.

Fig. 6. Nickel arsenide, NiAs . (Niccolite). The hexagonal unit cells are outlined in dotted lines. Valence coordinates are shown in full lines. Each cation (Ni) is surrounded by six anions (As) which are at the corners of a slightly distorted octahedron. Each anion has six cations surrounding it. These we may imagine at the corners of a trigonal pyramid.

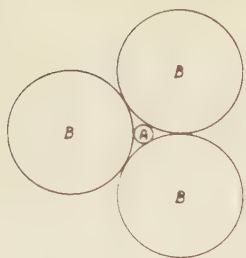


Fig. 1

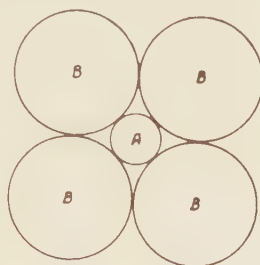


Fig. 2.

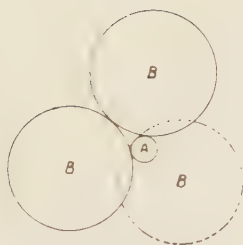


Fig. 3

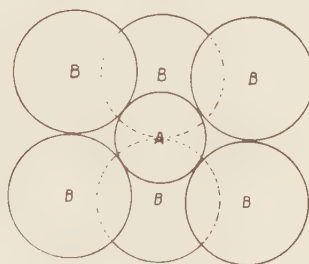


Fig. 4

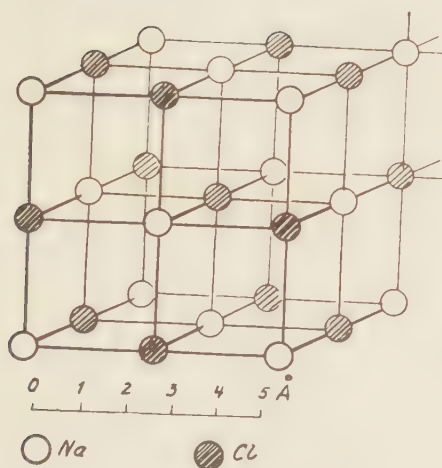


Fig. 5

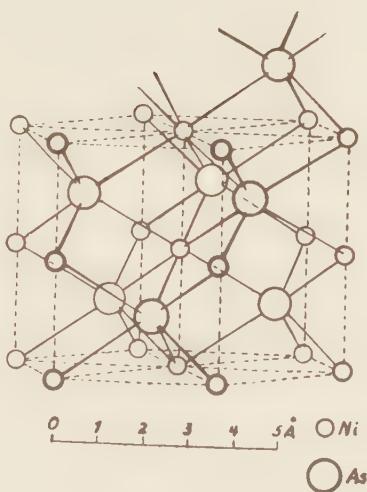


Fig. 6

- Fig. 7. Caesium chloride, CsCl . The cubic unit cell is shown in dotted lines. Eight valence coordinates connect each ion with its neighbors of opposite charge.
- Fig. 8. Zincblende, ZnS . The cubic unit cell is shown in dotted lines. The Zn atoms (or ions?) form a face-centered cube. The S atoms form a tetrahedron inside the cube in such a way that S atoms are placed in the centers of alternate octants. Each atom has four coordinates linking it to four atoms (or ions?) of opposite charge. These are at the corners of a tetrahedron. If we imagine all atoms to be alike in this structure we have the diamond structure type.
- Fig. 9. Wurtzite, ZnS . The hexagonal unit cell (rhombic in cross-section) is dashed. The valence coordinates are very similar to zincblende, four from each atom at the center of a tetrahedron to four atoms at the corners.
- Fig. 10. Chalcopyrite, CuFeS_2 . This structure is very similar to zincblende. The only difference is that half of the Zn atoms are replaced by Cu and the other half by Fe.
- Fig. 11. Fluorite CaF_2 . The calcium ions form a face-centered cube (dotted unit cell). The fluorine ions form a smaller cube inside. Each calcium has eight coordinates to fluorine ions and each fluorine four coordinates to the corners of a tetrahedron of calcium.
- Fig. 12. Cuprite Cu_2O . The O ions form a body-centered cube. The Cu ions form tetrahedrons around each O ion. The Cu ion has two coordinates, the O ion four.

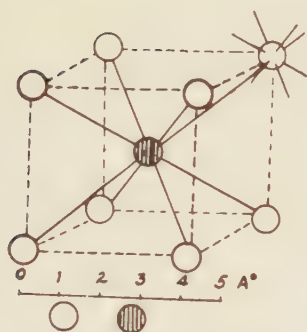


Fig. 7

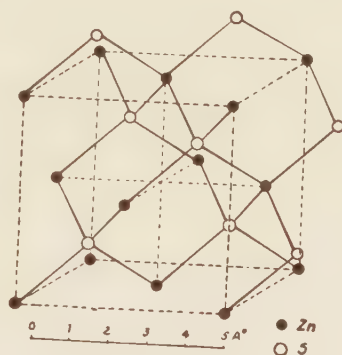


Fig. 8

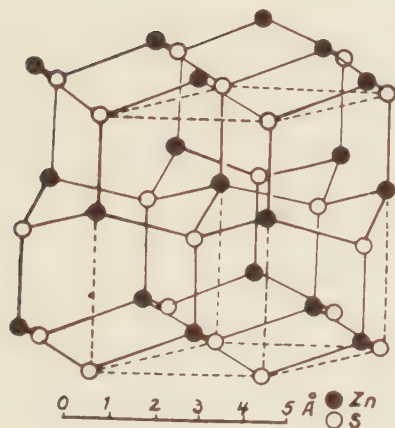


Fig. 9

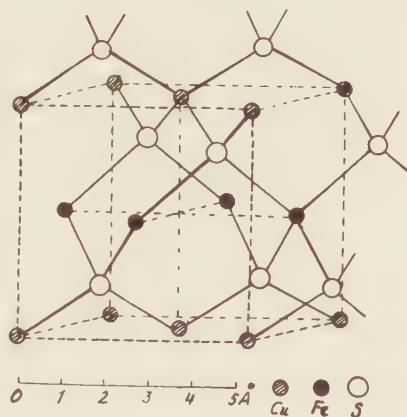


Fig. 10

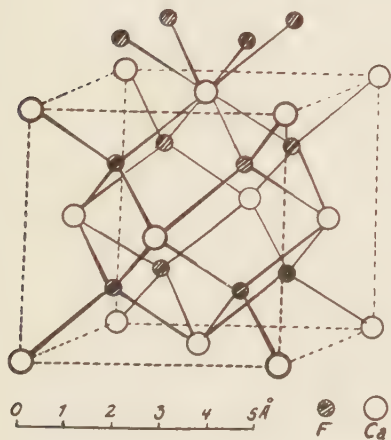


Fig. 11

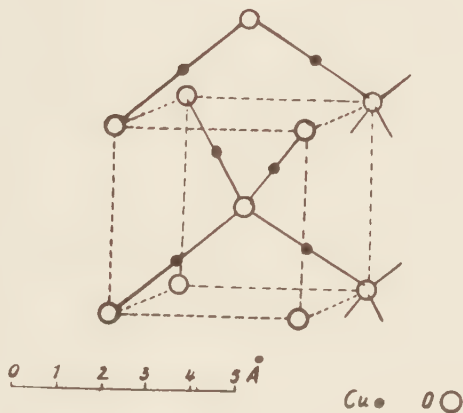


Fig. 12

- Fig. 13. Rutile TiO_2 . The unit body-centered tetragonal prism is dotted. Each T. ion has six coordinates to O ions which are at the corners of a slightly distorted octahedron. Each O ion has three coordinates.
- Fig. 14. β -cristobalite, SiO_2 . The cubic cell contains eight molecules of SiO_2 . Each Si ion is surrounded by a tetrahedron of four O ions. Each O ion has two coordinates to the two Si ions between which it is placed.
- Fig. 15. β -quartz, SiO_2 . The hexagonal prism shown is three times the volume of the unit cell which is one of the rhombic prisms outlined. Each Si ion has four O ions at the corners of a distorted tetrahedron. Each O ion lies between two Si ions but not in a straight line with them.
- Fig. 16. Boron nitride, BN. The hexagonal units are dotted. This is a "layer lattice." Each B ion has three coordinates to the N ions and each N ion three coordinates to the nearest B ions. Graphite has the same structure if we imagine all particles to be carbon.
- Fig. 17. Molybdenite, MoS_2 . A typical hexagonal "layer lattice." (Schichtengitter). The layers are outlined by stippled areas. On each side of a layer of Mo ions is a layer of S ions. Two S layers are in contact. The distance between these layers is greater than between the Mo-S layers. These two facts explain the easy basal cleavage of molybdenite. Cadmium iodide, CdI_2 , has a similar structure.

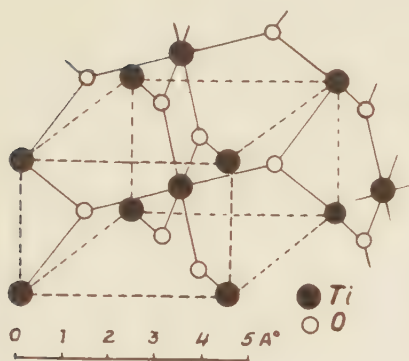


Fig. 13

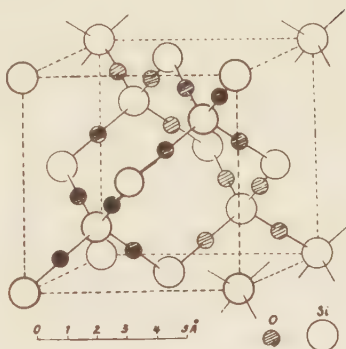


Fig. 14

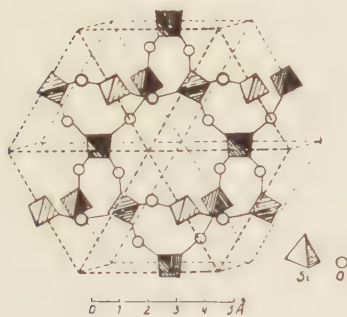


Fig. 15

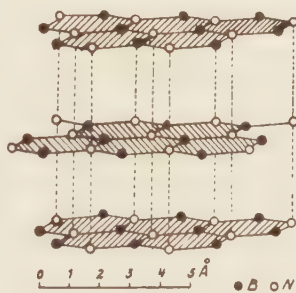


Fig. 16

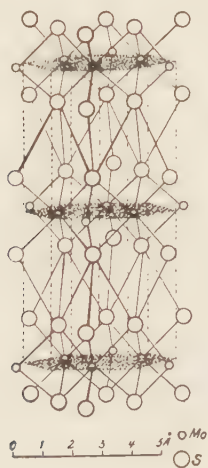


Fig. 17

AN X-RAY STUDY OF THE DOMEYKITE GROUP*

L. S. RAMSDELL, *University of Michigan.*

Domeykite, algodonite and whitneyite are usually considered as definite minerals, and have been assigned the formulas Cu_3As , Cu_6As and Cu_9As , respectively. However, various investigators have questioned the existence of these compounds, and have reported that microscopic examination reveals that these minerals are mixtures, rather than homogeneous compounds. In this present investigation, X-ray methods have been used to supplement the microscopic data, and rather conclusive information regarding these minerals has been obtained.

THE COPPER-ARSENIC EQUILIBRIUM DIAGRAM

The copper-arsenic equilibrium diagram has not been worked out completely. With high arsenic content the relations are complex, and the experimental difficulties become very great because of the volatility of the arsenic. However, the portion of the diagram which includes the compositions of domeykite and the others in this group is completely known.¹ A definite compound, Cu_3As , is formed, but there is no other compound between this and pure copper. About 4 per cent of arsenic can be present in solid solution in the copper. There is a eutectic with the composition Cu 78 per cent and As 22 per cent. Accordingly, in the range of compositions included in this investigation, it would be expected that the Cu—As solid solution and the compound Cu_3As would be the only two constituents present. With these as end members, any material of intermediate composition should consist of crystals of the predominating constituent embedded in a eutectic groundmass. The Cu-As diagram is shown in Figure 1.

In this investigation the equilibrium diagram has been completely checked, both by microscopic and X-ray methods. Examinations were made of polished sections from a large number of samples which were prepared with varying compositions and by different methods. X-ray photographs were made of most of these preparations.

* Paper presented at the ninth annual meeting of the *Mineralogical Society of America* at New York City, December 28, 1928.

¹ K. Friedrich. *Metallurgie*, 5, 529, (1908).

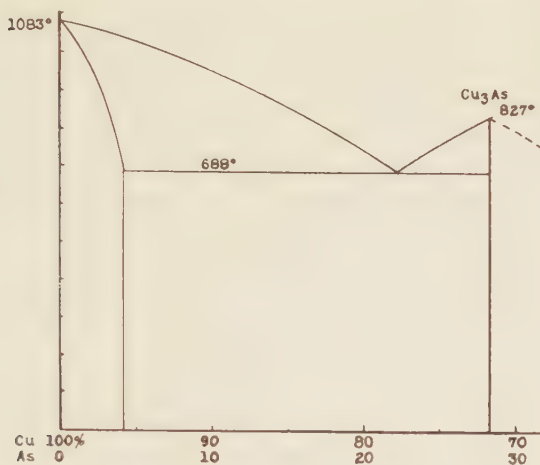


Fig. 1. Copper-arsenic equilibrium diagram.

A few samples of Cu_3As were prepared by passing arsenic vapor over hot copper, as described by Koenig.² The crystals obtained in this manner gave X-ray patterns identical with those obtained by fusion, and no further study of these was made. All of the other samples were prepared by fusion, either of copper and arsenic, or of the natural minerals. Fusions were made in small crucibles, with a protective covering of borax. In some cases the borax was melted by heating from above before heat was applied to the sample, in others the material to be fused was dropped directly into molten borax. Very little volatilization of the arsenic occurred, and only with prolonged heating was the copper oxidized sufficiently to color the borax. Samples could be fused in this manner with a loss in weight of less than 0.1 per cent.

In all cases the product obtained by fusion was such as would be predicted from the equilibrium diagram. The only constituents observed in polished sections were gray Cu_3As and the Cu-As solid solution, which had a pale cream copper color. For the sake of brevity this will be referred to as the pink constituent. The relative proportions of the pink and the gray, and the amount of eutectic, varied with the composition. Different heat treatments, varying from slow cooling to quenching, affected the grain size, but nothing was obtained except the pink and the gray constituents.

² *Zeit. Krist.*, **38**, 532, (1904).

Likewise, only two types of X-ray diffraction patterns were secured from these preparations—that of Cu_3As and of the Cu-As solid solution. These occurred either alone, or superimposed with differing relative intensities, depending upon the proportions of each constituent. The pattern from the Cu-As solution is almost identical with that of metallic copper, the only difference being that the spacings are slightly enlarged. This pattern and that of artificial Cu_3As are shown diagrammatically in Figure 2.

It was expected that with such definite data regarding the Cu-As diagram, the correlation of these data with those obtained from the natural minerals would be quite simple, but this was not the case. Numerous polished sections of the natural minerals have been studied, analyses have been made in some cases, and all have been X-rayed. The data obtained by these various methods are in agreement among themselves, but in general are not what would be predicted on the basis of the equilibrium diagram. The results from each of the three minerals will be discussed separately.

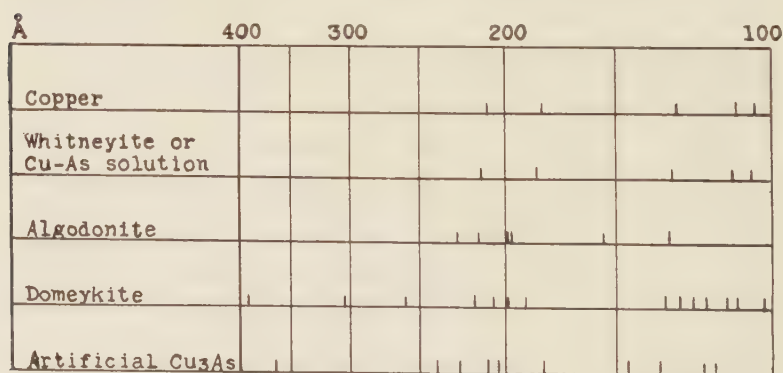


Fig. 2. Diffraction patterns of the various copper-arsenic compounds.

WHITNEYITE

Whitneyite is the only one of the three which gave results that can be directly correlated with the experimental data. Murdoch³ describes whitneyite as homogeneous, and apparently did not question the existence of a compound with the formula Cu_9As . Borgström⁴ reports that whitneyite consists of a mixture of algodon-

³ J. Murdoch. *Microscopic Determination of the Opaque Minerals*, p. 74.

⁴ L. H. Borgström. *Geol. För. Förh.*, 38, (1916); *Am. Mineral.*, 4, 91 (1919).

ite and copper, and denied the existence of a Cu_9As compound. The data obtained in this investigation are essentially in agreement with those of Borgström.

Two specimens of whitneyite were available for study. One was a portion of a large nodule from the Mohawk mine,⁵ and the other a large specimen from the Pewabic location, both in the Keeweenaw peninsula of Michigan. Numerous sections were cut off and polished. In every case the chemical analyses and X-ray photographs were made with material which had first been examined with the microscope.

Both specimens showed the same general characteristics. They were somewhat malleable, and fractured with great difficulty. The fracture surface was fine granular, and appeared homogeneous. On polished surfaces lack of homogeneity was apparent, sometimes even to the unaided eye. Two constituents were present, one pink and the other cream in color. The pink was similar to the Cu-As solution in appearance, and was identified as such both by the chemical analyses and the X-ray patterns. This identification was not difficult, because the pink constituent occurred in rather large areas, with very little admixture of the cream. Thin slices of the material were polished on both sides, after which the comparatively pure pink areas could be separated very readily. The cream constituent, however, was usually intimately mixed with the pink, and could not be obtained in pure form.

The X-ray pattern from the pink constituent was similar to that from the Cu-As solution. The cream, mixed with the pink, gives this same pattern, together with the stronger lines of the pattern which was obtained from the algonite specimens. Thus the X-ray evidence identifies the pink constituent as being the Cu-As solid solution, and the cream as algonite.

In the chemical analysis, the arsenic was determined as $\text{Mg}_2\text{As}_2\text{O}_7$, while the copper was determined electrolytically in alkaline solution; under such conditions traces of Ni or Co would also be deposited. However, a qualitative test for Ni was negative. In one specimen there were large cavities and stringers of some foreign material, while in the other the impurities were found in

⁵ The writer is indebted to Mr. F. F. Bradley, of Toledo, O., for this specimen of whitneyite.

minute cavities. The samples were freed from these as far as possible, and the following results were obtained:

PINK CONSTITUENT				
	I	II	III	Average
Copper	93.65	93.68	93.54	93.62
Arsenic	5.17	5.18	— —	5.18
				<hr/> 98.80

No attempt was made to determine the remaining 1.20 per cent of the impurities. Recalculated on the basis of 100 per cent, the proportions would be: copper 94.8 per cent and arsenic 5.2 per cent. This agrees very well with the values of copper 96 per cent and arsenic 4 per cent for the Cu-As solid solution, for there was present a slight amount of the cream constituent, with its higher arsenic content.

An analysis was also made on a specimen which appeared homogeneous to the eye, but which was clearly seen to be an intimate mixture of cream and pink when examined with the microscope. This gave results very close to the theoretical percentages for a compound with the formula Cu_9As . It may be that there is a eutectic between natural Cu_6As and the Cu-As solution, in which the proportions of copper and arsenic happen to correspond approximately to this theoretical ratio. An analysis of a specimen containing areas of such a eutectic might very readily be misinterpreted as indicating a definite compound, especially when it is remembered that the early analyses were made long before the development of a technique for examining opaque minerals with the microscope.

The original analyses were made by Genth⁶ in 1859, on material which he stated was selected with great care, and which was apparently quite pure. A second group of analyses by Genth was made on material noticeably unhomogeneous, containing visible algonite. It was assumed that a good separation of the whitneyite from the algonite had been obtained because the analyses checked with the earlier ones. Thus an analysis on material of questionable homogeneity was made the criterion for further separations.

⁶ F. A. Genth. *Am. Journ. of Science*, **27**, 400 (1859); **33**, 191 (1862).

The analyses of Koenig⁷ on material which he called semi-whitneyite, with copper about 94 per cent and arsenic 6 per cent, would indicate that his samples corresponded to the Cu-As solid solution.

ALGODONITE

Murdoch⁸ describes specimens of algonite as consisting of a mixture of unknown cream and gray constituents, with the cream in slight excess, and concludes that algonite is therefore not a definite compound. He also assumes that algonite and domeykite are similar.

Two large specimens of algonite were available for this investigation. One came from the Mohawk mine, and the other was found as "float" in Baraga County, Michigan. Both had a fine grained fracture and steel gray color. They are more easily fractured than the whitneyite specimens, but much less so than domeykite, which can be crushed quite easily.

Polished sections from these two specimens showed a homogeneous material of cream color, similar to the cream constituent of the whitneyite. There were small inclusions of quartz, a few small blebs of a pink material which appeared to be copper, and the Mohawk specimen showed small patches of an unknown gray substance. An insufficient amount of this material was present to make it possible to obtain an X-ray pattern. These inclusions were present in such small amounts that there seemed to be no reason to regard them as an essential part of the material, nor to regard algonite as anything but a homogeneous substance.

The X-ray pattern from algonite is entirely different from the patterns obtained from the artificial preparations. The Cu-As diagram would indicate that anything with a composition corresponding to Cu_6As should be a mixture of Cu_3As and the Cu-As solution in about equal proportions. As already indicated, the microscopic evidence was to the contrary, and the X-ray pattern likewise indicates that algonite is a naturally occurring compound, Cu_6As in composition, which is not duplicated in artificial preparations. Its pattern shows none of the lines characteristic of either artificial Cu_3As or the Cu-As solution. This is shown in Figure 2.

⁷ C. A. Koenig. *Zeit. Krist.*, **38**, 537 (1904)

Murdock, *loc. cit.*, p. 37.

The relation of this natural compound to the artificial material is shown by its behavior upon heating. When fused and cooled, this homogeneous compound breaks up into Cu_3As and Cu-As solution, just as would be predicted from the diagram. Actual fusion is not necessary. When heated to a point somewhat below the fusion point, the decomposition occurs and the pink and gray constituents are formed. This is in agreement with Borgström,⁹ who reported that algodonite is unstable at its melting point, and changes to copper and Cu_3As .

DOMEYKITE

Murdoch¹⁰ describes domeykite as a mixture. Three specimens examined by him were composed of unknown cream and gray constituents, identical with algodonite, while a fourth showed cream and purple constituents. No such results were found in the specimens examined in this investigation. Physically the domeykite is quite different from algodonite, and except for small inclusions, the polished sections seemed to be homogeneous.

The constancy of the analyses and the identical X-ray patterns of specimens from widely different localities argue against domeykite being a mixture, for in such a case it would be expected that the proportions of the two constituents would vary. Likewise, if domeykite were a mixture with an average composition of Cu_3As , one component would have to be higher, and one lower in copper, than the compound Cu_3As itself. But the X-ray pattern shows no lines corresponding to the Cu-As solution, or to algodonite; nor to the artificial compound with lower copper content which was obtained in some of the preparations, and which was probably Cu_5As_2 . If domeykite is a mixture, it must be composed of compounds different from any of these.

The X-ray pattern of domeykite is not only different from the compounds with higher and lower content of copper, but is also different from that of artificial Cu_3As , which indicates that the compound Cu_3As is dimorphous. Both forms are stable at ordinary temperatures, and there is a monotropic inversion from domeykite to the artificial form at a temperature close to the melting point of domeykite. If natural domeykite is fused, or heated nearly to

⁹ *loc. cit.*

¹⁰ *loc. cit.*, p. 37.

the fusion point, it inverts to the other form, and does not change back upon cooling. This change is shown by the X-ray patterns, and also by the microscope. The cream colored domeykite changes to gray, and there is formed a small amount of the Cu-As solid solution, occurring as interstitial material between the grains of gray Cu_3As . This does not mean that domeykite contains excess copper over that required by the formula Cu_3As , but rather is an illustration of the fact that the artificial compound always seems to be slightly high in arsenic.

As previously stated, the crystals of Cu_3As prepared by passing arsenic vapor over hot copper are identical with the material prepared by fusion. Accordingly the crystallographic data, as determined by Wright¹¹ on crystals prepared in this manner, are not applicable to domeykite. In this investigation, however, no new data for domeykite were obtained. As far as its behavior in reflected polarized light is concerned, domeykite is isotropic, but its X-ray diffraction pattern does not agree with any simple cubic structure.

A single X-ray photograph was taken on a sample of mohawkite, and the pattern secured was indistinguishable from that of domeykite. No further study was made, but it seems probable that its character is quite analogous to that of domeykite.

SUMMARY

1. According to the copper-arsenic constitution diagram, the only compound in the range from Cu 70 per cent-As 30 per cent to pure copper is Cu_3As . Copper may contain 4 per cent of arsenic in solid solution.

2. A series of artificial preparations, made chiefly by fusion of copper and arsenic in proper proportions, was in entire agreement with the diagram, as shown by microscopic examination and X-ray photographs. No constituents but Cu_3As and Cu-As solution were found.

3. Whitneyite, Cu_9As , is not a definite compound, but a mixture of algodonite and Cu-As solution.

4. Algodonite, Cu_6As , is a definite compound, but is unstable at its melting point, breaking down into Cu_3As and Cu-As solution, and therefore cannot be prepared artificially by fusion.

¹¹ F. E. Wright. *Zeit. Krist.*, **38**, 551 (1904).

5. Domeykite, Cu_3As , is a definite compound, also unstable at its melting point. At this temperature there is a monotropic inversion to a dimorphous form, which corresponds to the Cu_3As compound formed in artificial preparations.

While this article was in press, there appeared a paper "ALGODONITE AND WHITNEYITE" by F. Machatschki in *Neues Jahrb. Mineral., Bl. Bd., LIX*, Abt. A., 137-158 (1929). This new investigation confirms the conclusion that there is no Cu_9As compound. The specimen of whitneyite studied showed 60% of the Cu-As solution and 40% of a substance with a hexagonal structure. A specimen of algodonite had the same constituents in the proportion of 20 and 80 per cent, respectively. In my investigation only three well defined lines were present on the algodonite films, and no attempt was made to determine the structure. I find that these three lines, together with four other very doubtful ones agree with those obtained by Machatschki on his films. The structure he derives is hexagonal close-packed, with two atoms in the unit cell. The Cu and the As atoms are assumed to be equivalent, and are distributed in the ratio of 5 to 1. It is suggested that possibly there is a range of compositions in which this structure is stable.

This is quite possible, but his conclusion that the hexagonal compound is Cu_5As rather than Cu_6As does not seem justified. Instead of the obvious conclusion that his specimen was a mixture of algodonite (Cu_6As) and the Cu-As solution, he assumes that it is typical algodonite, and that this mixture has a composition corresponding to Cu_6As . Since 20% of the mixture is Cu-As solution, with Cu 95% and As 5%, he figures that the remainder must have Cu and As in the ratio of 4.9:1. His conclusion is that the hexagonal compound is Cu_5As . It would seem that such a conclusion should be based on an actual analysis of the specimen used. Algodonite does occur in comparatively pure form, and an analysis of such material in my investigation gave Cu 83.2% (theoretical for Cu_6As is Cu 83.5%.)

ON NAMING MINERALS

H. E. MCKINSTRY, *West Chester, Pennsylvania.*

One can join most heartily in Professor Eakle's appeal for more thought in the naming of minerals.¹ His plea to continue immortalizing in stone (so to speak) the leaders of the science can only meet with general approval. With him we regret that the rules now in vogue require certain eminent mineralogists to remain unhonored in this manner because, through no fault of their own, their namesakes' names have turned out to be synonyms. We rejoice that no one can become familiar with mineralogy without being frequently reminded, through the nomenclature, of Werner, Wollaston, Silliman and Dana.

While applauding the judicious use of personal names, one is forced to admit that at times they may cause difficulties to those of other nationalities than that of the scientist in question. Thus smithsonite, simple enough for an Anglo-Saxon, contains a "th", unpronounceable for a Frenchman or a German and an initial "sm" which would appall a Spaniard, just as we ourselves may at times be at a loss as to how to cope best with ännerrödite, gmelinite, häüynite and szmikite.

Desirable as personal names may be, there is little to be said for an attempt, at this late date, to make mineralogical nomenclature rigidly uniform. Were we, like Adam in the Garden, confronted with a world of unnamed things, it would be our glorious opportunity and sacred duty to name them systematically. But fortunately or unfortunately, all of the fifteen hundred minerals now known are already named and certainly no one would propose to re-christen them in violation of all laws of priority. Any struggle for uniformity would at best effect only the species yet undiscovered—probably in the main a relatively small number of the less common ones. The new standardized names would be lost in the forest of older heterogeneous ones, the increased uniformity would be barely perceptible and in just what way would science be benefited?

It would seem that really the most desirable object would be to aid the suffering student who, as Professor Eakle says, is confronted with a formidable array of names to master. To him, any

¹ *Am. Mineral.*, vol. 13, p. 533.

name which even remotely suggests some characteristic of the mineral is little short of a godsend. And therein lies the great boon of physical and chemical connotations. Though we Americans, fostered in a utilitarian contempt for the classics, have, like Shakespeare, "small Latin and less Greek", these languages possess at least the advantage of being in some degree international. An educated person needs no great linguistic training in order to recognize that "ortho" suggests "straight" and "clase" suggests "break" or "cleavage." What name could be more descriptive than tetrahedrite unless it be azurite, not to mention hematite, magnetite, pyrite, and the less obvious cyanite, actinolite, and staurolite?

But perhaps the chemical names are the most suggestive of all. What matter if they do not express the composition in detail? Nothing short of a formula could do this. Consider the mental associations aroused by the words argentite, cuprite, bismuthinite, cobaltite, fluorite, and dozens of others; or by the compound chemical-and-physical names: arsenopyrite, cerargyrite, pyrargyrite. Barytocalcite may be cumbersome but at least it signifies something which is more than could be said had its discoverer been forced by a convention to name it, let us say, mcgillicuddyite (keeping unmutilated the name of a not impossible scientist).

It is truly regrettable that chalcophanite contains no copper, and that hydrocyanite is anhydrous, but is this an indictment of the practice of deriving names from chemistry? Say rather that the fault lies in the failure to derive these names chemically. As well abandon the ending "-ite" altogether because some misguided person has made use of it in naming a widely advertized antiseptic which is not a mineral!

While mines are ephemeral and many place names signify nothing, one may even defend certain names based on localities: atacamite suggests the Chilean desert whose dryness alone is responsible for the preservation of the mineral; vesuvianite suggests the volcanic emanations from whence it sprung; labradorite suggests the bleak cliffs of deep-seated intrusives which have afforded the beautiful feldspar.

Thus, since complete uniformity cannot be attained without throwing overboard a thousand names in common usage (atrocious as some of them are), let those who have the good fortune to

contribute to the nomenclature be merciful and discrete in naming the children which are still to be born to mineralogical research. Let their names do honor where honor is due; let them be euphonious if possible, universally pronounceable if possible, short if possible, but above all, let them be significant and appropriate. In short, this paper, while not in any sense an outcry against the use of personal names is intended as a mild plea for the retaining of such rich sources as may be found in the fields of chemistry, physics, geography and the classical languages.

NOTES AND NEWS

AN UNUSUAL COLLEGE MONUMENT

C. A. BONINE, *Head, Dept. of Geology and Mineralogy, Pennsylvania State College.*

Every known variety of Keystone State building stone, assembled from Pennsylvania's 80,000 square miles of earth's crust, may be seen on the Pennsylvania State College campus in a "monument," known as the Polyolith, which is only six feet square at the base. The Polyolith is so constructed that the rock formations of the State, arranged in exactly the same order in which they occur in nature, may be seen at a glance.

The Polyolith, erected 33 years ago, consists of 281 samples of stone procured from almost 150 localities of Pennsylvania. Its chronological series of rocks, measuring 33 feet in height, represents a span of millions of years in the geological formation of the earth's crust of Pennsylvania. The weight of the column is calculated to be approximately fifty-three and a half tons. Because it tells how various stones withstand weathering, the "monument," as it is known to students, attracts building specialists and geologists from all parts of the country.

An examination of the Polyolith in its present condition reveals that there are approximately 25 different rocks that have withstood atmospheric alterations exceptionally well and 36 that have undergone only a very slight change. Students of geology who have examined the Polyolith and studied the changes which have taken place in the rock formations, have classified the various stones according to their adaptability for building purposes, based on appearance, texture and durability.

AN UNIQUE FORMATION OF SATIN SPAR

VICTOR G. HILLS, *Skouriotissa, Nicosia, Cyprus.*

Here in the ancient mine at Skouriotissa which had been closed for at least 1500 years is found a most odd formation of satin spar crystals which have grown since the workings were closed. Fig. 1 is a photograph taken in the ancient drift. Fig. 2 shows a handful of the crystals scattered on a black cloth. These long clear white, hair crystals stood out each independently, growing from the faces of the mine drift, from either top, bottom or sides. I measured one 13 inches long. Nine inches is a common length. Their diameter is from 0.05 to 0.12 millimetre; the longer hairs being commonly about 0.1 millimetre. They are somewhat flexible, the more slender bending to a half circle of one inch diameter. Some bent crystals may be seen in the photograph. Large handfuls, probably the longest and best, were gathered in bunches and brought to the office before I had a chance to take the photograph.

In Fig. 2 is also shown an odd cluster of somewhat coarser crystals attached to a piece of rock and standing just as they grew from the bottom of the drift. Note that the top looks like a bunch of cords which had been broken off by twisting. That the crystallization should take a spiral form, even so slightly, seems the strangest thing of all about this odd formation.

At other places where ancient workings are broken into there are found transparent selenite crystals usually from 1/16 to 1/8 inch thick and from 1-1/2 to 2-1/2 inches in length. These crystals have developed singly and without any sort of orientation.

Occasionally the gypsum has formed stalactites as clear as icicles and reaching five inches in length.

The hairy formation has been found only in one place and extended along the drift for about ten feet. The other formations have been found in several of the old drifts but only sparingly.

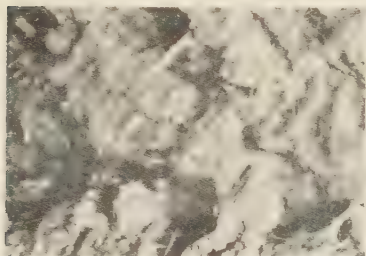


FIG. 1

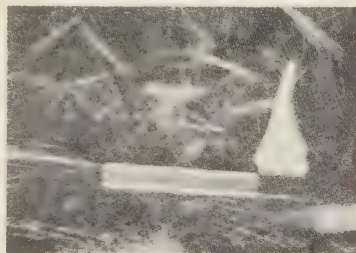


FIG. 2

Quite recently another ancient drift, disclosing an entirely different crystalline formation, has been cut. This drift is sufficiently open to permit entrance for about 40 feet. Both ends terminate, as usual, in cave fills. This gallery has its top, bottom and sides lined with a clumpy formation of hydrous iron and copper sulphates. The crystals are in such complex masses that it is not practicable to separate clean crystals for determination, but an off-hand observation discloses the following minerals as possibilities: coquimbite, melanterite, phillipite and chalcantite. The coquimbite predominates as amethystine tinted crystals. Whether the beautiful purple, blue and green colors will be retained in free air remains to be seen. All of the formations are soluble in cold water. I note that Dana gives phillipite as soluble in water but unaffected by exposure to air. When the drift was first opened it was devoid of oxygen, but after a few hours a light would burn. An antique clay lamp was found in this drift.

The recent mine workings occasionally disclose bunches of nearly pure chalcantite. On exposure to the air these turn white.

THE LARGEST METEORS

A seventy-ton meteor is reported to have been found at Otjihaene, near the head of the Grootfontein railway in the northeastern part of Southwest Africa, imbedded in soft limestone. Its approximate size is ten by ten by four feet. Though this is said to be the largest meteor ever actually discovered in the world, it is probably dwarfed by the one which many years ago caused the famous Meteor Crater in Arizona. This is the opinion of Dr. George P. Merrill, of the U. S. National Museum. The great meteor which fell in the Yenissei Province of Siberia on June 30, 1908, was also probably much larger, but as yet the main part of neither of these meteors has been located. Another huge crater, caused by a meteor that fell at some time in the past, was discovered in the Pamir, in Central Asia, near Afghanistan. This latter crater is a conical pit 260 feet in diameter and 33 feet deep.

The 1908 Siberian meteor is probably the largest that has ever struck the earth. The region of the fall is marshy and more than a mile in diameter. The ground is pitted with deep funnels from 50 to 100 feet in diameter, so that probably the meteorite, with a weight estimated at half a million tons, burst to pieces, bombarding the earth with fragments. At the towns of Kerensk and Ilimsk, 250 miles away, great detonations were heard and pillars of smoke and fire were seen. Railroad officials at Kansk, 400 miles distant, felt the air wave and heard a roaring sound, while the seismographs at Irkutsk, 900 miles away, detected the vibration of the earth when it hit.

Though no human beings happened to be in its path, one herd of 1,500 reindeer belonging to a farmer was annihilated. Only a few scorched carcasses remained. Houses were badly damaged and metal utensils were melted. Trees on surrounding hills were scorched and knocked over; they can still be seen with their tops pointing away from the center. An expedition sent out by the Soviet Government studied the general character of the region. Later borings will be made for pieces of the actual meteorite. This is the first authenticated time that a meteorite did damage to man or animals. It is fortunate that it fell in such a sparsely settled region and not in a large city like New York or London.

"Science," Mar. 22, 1929.

E. E. HESNARD

Emile E. Hesnard, a charter member of the Mineralogical Society of America, died February 17, 1929, at his home in Keystone, South Dakota, at the age of 61 years. With his passing the Black Hills lost its most diligent collector and science an earnest mineralogist. Not having had an extended classroom education in geology and mineralogy, Mr. Hesnard was hesitant about publishing articles on the minerals occurring in his vicinity, but the visitors to the region could not help but be impressed by the depth of his knowledge of Black Hills mineralogy. Mr. Hesnard worked for many years at the Etta mine, and in recent years had been superintendent of mining operations at the nearby Hugo and Peerless pegmatites. Many field superintendents have an uncanny skill in distinguishing the mineral species with which they come in contact, but Mr. Hesnard went very much farther and by ceaseless reading and personal observations became extremely well acquainted with the genetic theories and their local application. Anyone interested in the processes of mineralization of the Keystone pegmatites found inspiration through acquaintanceship with Mr. Hesnard. During his many years in the district he gathered together an imposing collection. He sold specimens to the mineral-distributing firms, but being a true mineral lover he much preferred to trade with collectors from other localities. In addition to his keen mental ability, Mr. Hesnard was an extremely likeable gentleman and was loved by all who knew him.

Mr. Hesnard was born at Flers, France, November 14, 1867. Upon graduating from a local academy at the age of fifteen he accompanied his father to the United States, going directly to Dakota territory and settling near the present site of Hermosa. During the next few years, he lived the life of a pioneer, breaking in the soil and raising cattle. However, he soon became interested in mining and moved to Keystone, where he worked and lived for the greater part of his life. He leaves a wife and three grown children.

In 1925 Mr. Hesnard published a paper in the *Black Hills Engineer*, Journal of the South Dakota State School of Mines at Rapid City, entitled "The Mining of Feldspar near Keystone."

KENNETH K. LANDES

Herbert P. Whitlock, curator of minerals and gems at the American Museum of Natural History, New York City, has been appointed honorary curator of mineralogy at the Wadsworth Atheneum and Morgan Memorial, Hartford, Connecticut.

Dr. J. J. Sederholm, director of the Geological Survey of Finland, who was recently awarded the Penrose medal by the Geological Society of America, gave a series of twelve lectures at the University of California on the "Pre-Cambrian problems in Fenno-Scandia."

Dr. K. Spangenberg of Kiel has accepted the professorship of Mineralogy at the University of Würzburg.

The following eminent geologists have died during the latter part of 1928:

John A. Bownocker of Ohio State University and director of Ohio State Geological Survey, on October 20, age 63 years.

T. C. Chamberlain, emeritus professor at the University of Chicago, on November 15, age 85 years.

J. C. Diller, for 41 years a member of the U. S. Geological Survey, on November 13, age 70 years.

Joseph Lukaszewicz, professor at the University of Wilna, age 65 years.

Dr. Michael, director of the Prussian Geological Survey and honorary professor at the Techn. Hochschule at Charlottenburg, on October 30, age 59 years.

W. N. Rice, emeritus professor at Wesleyan University, on November 13, age 83 years.

E. H. L. Schwarz, professor at Rhodes University, Grahamstown, South Africa, on December 19, age 45 years.

The following have retired from active duty:

J. A. Bancroft, professor of Geology, McGill University.

Dr. Bruhns, professor of Mineralogy at the Bergakademie at Clausthal.

K. Bush, professor of Mineralogy at the University of Münster.

Dr. Emil Ernst of the University of Heidelberg has been called to the University of Münster to fill the vacancy caused by the retirement of Dr. K. Bush.

Dr. H. Steinmetz of the Bergakademie at Freiberg in Saxony has been offered the professorship of Mineralogy at the Techn. Hochschule at Munich.

Those in charge of the Journal wish to suggest that every effort be made by contributors possessing unfinished articles to complete the manuscripts and send them to the Editor before leaving for field work. By so doing it is hoped that sufficient material might be accumulated to insure undelayed issues throughout the summer months.

REVIEWS

KRYSTALLOGRAPHISCHE UND STRUKTURTHEORETISCHE GRUNDBEGRIFFE. P. Niggli. Handbuch der Experimentalphysik, Bd. 7, t. 1. 317+xii pp., 131 figs. Akademische Verlagsgesellschaft M. B. H. Leipzig, 1928. Price 32.50 marks.

The nature of this work is well set forth in the author's preface, which may here be translated in part: "Corresponding to the purpose of the *Handbuch der Experimentalphysik*, the presentation of the geometrical foundations of crystal-calculation and crystal structure-determination proceeds from the structure of crystals. It has not been possible to develop all formulas and relations in detail. The fundamental principles are elucidated, and beyond that it is attempted to render the book usable in practice by comprehensive summary presentations. For crystal calculation all the important formulas are collected in a few specified places.

"The book contains a series of new viewpoints, which may prove important in further structural-geometric investigations. For example, the reduction of quadratics is treated in full detail. In the presentation of symmetry-properties new plans are introduced. The rules of selection (*Auswahlregeln*) have been taken as fundamental, and topologic structure-analysis is treated as to its characteristic features.

"Literature references are appended to each chapter. These naturally make no claim to completeness, but will nevertheless suffice for orientation in the different modes of treatment of problems at hand. Especially full are the references to older works, so that historical developments, not specially treated in the text, can be traced. Many of the figures are wholly new although some are taken from other works."

The eight chapter headings are: 1. The general geometrical properties of crystals and crystal-space. 2. General calculation and graphical treatment of crystallographic problems. 3. Specialization of translation-groups. 4. Special crystallographic relations of the lattice-types. 5. The special symmetry of crystal-space; the analytical-geometrical investigation of space-systems. 6. The homogeneous lattice complexes, the structure-vector, and the rules of selection. 7. Topologic structure-analysis. 8. Aids in geometric structure-analysis.

The book will be useful to all crystallographers working along modern lines of space-group theory. Like all of Niggli's works (how does he manage to write so many?) it gives evidence of great care in preparation, and ingenuity in mode of presentation of abstruse mathematical ideas. It is an important contribution to crystallographic literature.

EDGAR T. WHERRY

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB

Minutes of the February Meeting.

A regular monthly meeting of the New York Mineralogical Club was held at the American Museum of Natural History on the evening of February 20, 1929, with Vice-President George E. Ashby in the chair. Twenty-six members were present.

Mr. Philip Krieger, Mr. Arthur Montgomery, and Miss Mary B. Sayles, of New York City, and Mr. Alexander F. Mitchell of Hartsdale, N. Y., were elected to membership.

The Club voted to contribute \$50 from the treasury to the fund for the support of the family of the late Prof. Tschermak of Vienna.

Dr. Paul F. Kerr, of Columbia University, a former president of the Club, addressed the meeting on "*Observations and Collections at the St. Francis Dam, California.*" This dam was located on the San Francisquito Creek, and impounded part of the water supply of the city of Los Angeles. The dam failed and caused great loss of life and property damage in the valley below. The failure was not due to faulty construction of the dam itself, but to failure to consider the properties of the rocks on which it was built. One end of the dam rested upon the Sespe Sandstone, which contains an appreciable quantity of gypsum, a mineral soluble in water. The other end was built upon the surface of a schist whose platy structure was parallel to the side of the canyon, permitting the rock to pull apart under stress.

The lecture was illustrated with many lantern slides and with specimens of the rocks. Specimens of pyrite in coal from the mines near Scranton and Wilkes-barre, Pa., were also exhibited by one of the members.

HORACE R. BLANK, *Secretary*

NEW YORK MINERALOGICAL CLUB

Minutes of the March Meeting

A regular monthly meeting of the New York Mineralogical Club was called to order by the president, Dr. Herbert P. Whitlock, at the American Museum of Natural History on the evening of March 20, 1929. Fifty-three members and guests were present.

Mr. Ernest E. Fairbanks, of New York City, and Miss Sallie Mitchell, of Yonkers, N. Y., were elected to membership.

A nominating committee was elected to nominate officers for the year 1929-30, to be elected at the Annual Meeting in April.

The speaker of the evening, Mr. L. H. Bauer, of the New Jersey Zinc Company, was then introduced, the title of his address being, "*A Practical Treatise on the Minerals of Franklin and Sterling Hill, New Jersey.*" Of the 140 minerals now listed as occurring at these localities, Mr. Bauer confined his remarks to the following 16, which he considers the most important.

ORE MINERALS

Franklinite
Willemite
Zincite
Calamine
Chalcophanite

WASTE MINERALS

Calcite
Garnet
Rhodonite (bustamite and fowlerite)
Mica (manganophyllite)
Feldspar (hyalophane)
Pyroxene (schefferite)
Amphibole
Tephroite
Hancockite
Sphalerite
Gahnite

Each of these was discussed in detail, unusual and little known characteristics of the material found at Franklin being given particular attention.

At the conclusion of his talk the speaker demonstrated the fluorescence and phosphorence of certain Franklin minerals under the ultra-violet light. The lecture was also illustrated by means of a large number of fine specimens. Crystals of franklinite showing the cube modifying the octahedron, pale green crystals of sphalerite, and blue willemite were a few of the unusual exhibits.

The meeting adjourned with a vote of thanks to Mr. Bauer for his very interesting address.

HORACE R. BLANK, *Secretary*

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, March 7, 1929.

A stated meeting of the Philadelphia Mineralogical Society was held on the above date with the president, Mr. Trudell, in the chair. Forty-seven persons, including thirty-eight members were present.

Upon favorable recommendation by the council, the following were elected junior members: Messrs. F. Becker, and Rolin Harrold. Mr. Toothaker proposed Mr. Ruben Lobel for active membership. Mr. Cienkowski proposed the following for junior members: Messrs. Theodore Gran, and F. Schwan.

Mr. O. Ivan Lee addressed the Society on "*The Chemistry and Mineralogy of Hafnium.*" Details regarding the discovery of element No. 72 were given, introductory to a description of the chemistry of this element. The methods of separating it from zirconium were outlined, and attention called to the occurrence of hafnium in various zirconium minerals, particularly in zircon, cyrtolite, and eudialyte. This interesting address was illustrated by a large number of minerals containing hafnium, by lantern slides and specimens of some of the first salts prepared by Coster and Hevesy, and by a lead dish used by James, one of the first American chemists to work with hafnium. A rising vote of thanks was given the speaker.

Dr. Newcomet discussed briefly the preparation of radiographs. Mr. Cienkowski outlined a proposed competitive exhibit of minerals by the High School students of Philadelphia. The chair appointed Messrs. Biernbaum, Toothaker, and Arndt as a committee to report on the project.

SAMUEL G. GORDON, *Secretary*